Abstract
Continuous Casting Machines for large round sections have found worldwide interest and lately several plants have been put into operation. The reasons behind this development are the improved quality, the more economic process, the higher yield and the more homogeneous product that the continuous casting can deliver compared to the traditional ingot casting. The quality of the continuous cast bloom with regard to steel cleanliness and symmetry of the solidification structure can be improved even more by implementing the recently developed SMS Concast Vertical Semi-Continuous Casting Machine (VERSCON) concept. This process combines the cleanliness and radial solidification symmetry of ingot casting with the higher axial symmetry of the bloom, higher yield and lower operating cost of continuous operation. Furthermore even steel grades that are impossible to cast on a bow type caster, due to their surface crack sensitivity, can be cast with the VERSCON concept, as no straightening is involved. This concept specifically targets limited annual productions of highly specialized high value-added steel grades and is the perfect match for small ingot shops which aim for a higher yield and uncompromising quality. Bow type continuous casters for large sections on the other hand are the perfect match for producers seeking the optimal compromise between high productivity, low operating costs and stringent quality requirements.

Thus, the different requirements of steelmaker's worldwide lead to a tailor made design for continuous or semi-continuous machines according to the market volume and final product portfolio. The design of these casters is explained in this paper with special focus on the largest bloom caster ever put into industrial operation. This caster is presently producing in Asia and was commissioned by SMS Concast in 2016.

The results achieved in this continuous caster for rounds in the size range from 300 mm to 1,000 mm and the associated metallurgical processes are compared with concepts introduced for VERSCON machines together with the potential these products might have in the ASEAN market

Keywords
Advanced technologies for the casting of slabs, blooms and billets, modernization and new implementations, new developments in casting technologies

1. Introduction
In the last ten years several continuous bloom casters for large round sections have been installed worldwide especially in China and South Korea where many plants have been put into operation. The reason behind this trend is the necessity to move from the less profitable ingot casting operation to the continuous casting process that grants a better soundness of the product improving the quality of large forged pieces and a higher material yield that makes the investment more profitable.

In the present paper the design of continuous casters vs. semi-continuous casters for the production of very large up to oversize blooms, with special reference to the largest continually cast bloom ever put into industrial service, have been analyzed as part to this technological trend. The engineering challenges and the metallurgical considerations that led...
to this successful start-up have been related to the ideas developed for VERSCON casters with interesting results.

In October 2016, SMS Concast (part of the SMS Group) put into operation a continuous caster for rounds, with a very wide product size range from Ø300mm to Ø1,000mm at the new meltshop of Taewoong in Busan, South Korea. The objective of the new plant is to free the group from being dependent on the ingot market price and availability by producing their own blooms. Taewoong in fact is one of the world leading manufacturers of forged metal products and specialized in open die forging and ring forging mainly dedicated to green technologies such as wind mill turbines.

The new continuous casting machine was commissioned in October 2016 starting with section Ø410mm followed by the larger sections Ø600mm, Ø800mm and lastly the massive Ø1000mm that has been commissioned in January 2017.

2. CCM description

Table 1: The following table shows the main technical features of the new oversize bloom caster.

<table>
<thead>
<tr>
<th>Number of strands</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Limit</td>
<td>Strand 1, 3:Ø 300 – 1000 mm; Strand 2: Ø 300 – 600 mm</td>
</tr>
<tr>
<td>Sections Sizes Supplied</td>
<td>Ø310, Ø410, Ø600, Ø800, Ø1000 mm</td>
</tr>
<tr>
<td></td>
<td>The CCM can cast different section sizes simultaneously</td>
</tr>
<tr>
<td>Casting speed</td>
<td>0.1 m/min to 1.2 m/min</td>
</tr>
<tr>
<td>Length from meniscus to torch cutting machine</td>
<td>Approximately 47 m</td>
</tr>
<tr>
<td>Ladle support</td>
<td>Butterfly ladle turret with lifting/lowering and weighing facilities</td>
</tr>
<tr>
<td>Tundish transport</td>
<td>Overhead tundish car with lifting/lowering and weighing facilities</td>
</tr>
<tr>
<td>Flow control</td>
<td>Electromechanical stopper mechanism with actuation feedback</td>
</tr>
<tr>
<td>Mould level control</td>
<td>Eddy current system for large blooms, Co60 radiometric system for small blooms</td>
</tr>
<tr>
<td>Electromagnetic stirrers</td>
<td>M-EMS + F-EMS</td>
</tr>
<tr>
<td>Mould oscillation</td>
<td>Hydraulic tandem resonance oscillation, frequency and stroke remote adjustable</td>
</tr>
<tr>
<td>Secondary cooling</td>
<td>Air-Mist cooling for very low cooling intensities</td>
</tr>
<tr>
<td>Surface heating system</td>
<td>Flameless surface heater</td>
</tr>
<tr>
<td>Withdrawal straightening (WSU)</td>
<td>6 double WSU modules for Dynamic Mechanical Soft Reduction</td>
</tr>
<tr>
<td>Dummy bar system</td>
<td>Chain dummy bar for top feeding</td>
</tr>
<tr>
<td>Bloom cutting</td>
<td>Automatic torch cutting machines</td>
</tr>
<tr>
<td>Tertiary cooling</td>
<td>Slow cooling pits</td>
</tr>
<tr>
<td>Automation</td>
<td>Level 1, Level 2</td>
</tr>
</tbody>
</table>
The CCM has an annual capacity of 600'000 tpy and is designed to cover the full range of steel grades from carbon and alloyed steel grades to stainless steel (AISI 300 and 400 series) that are produced through the meltshop route. The larger sections being Ø800 mm and Ø1000 mm are the ones that will be more required since the main aim is switch from ingots from the market to the products cast in house. Nevertheless, smaller sections can be produced to target the possible market changes and produce carbon, alloyed and OCTG grades for the automotive and oil industry.

Fig. 1: Colling chamber view during casting Ø1000 mm on two strands

3. Special technological features

In order to meet the numerous requirements in terms of quality and productivity the following dedicated design measure have been adopted for this very special CCM:

**Productivity and machine outfit:** The calculated productivity for the various sections per strand ranges from 40 t/h to 52 t/h. In order to meet the meltshop productivity there is no need to equip all the strands for all section sizes. Strand 1 and 3 are in fact designed to cover the complete casting range while the strand number two, the one located in the middle, can only be utilized when sections below Ø600 mm are planned to be produced. This solution improves the design of the caster head while simultaneously reducing the investment due to the reduced strand distance: smaller tundish, smaller platform, smaller tundish cars, etc. Furthermore, the smaller middle strand has a lower equipment cost.

**Common oscillation:** Even though the castable sections are different among the strands the design of the tandem hydraulic oscillator is identical for all the strands providing a commonality of spares. Concerning stirrers external M-EMS is foreseen for the smaller sections (Ø310mm, Ø410mm, Ø600mm) while for the larger sections (Ø800mm, Ø1000mm), the M-EMS is not supplied. Air-mist nozzles are provided in the secondary cooling to feed the very low cooling amounts required by the large sections and high-alloyed grades. After the mould, a section-dependent containment sector provides accurate guiding for the strand and for the dummy bar.
**Heating system:** for the larger sections it is essential to induce a controlled increase of the surface temperature before straightening to avoid surface and sub-surface defects due to the relatively cold skin temperature compared to the core of the bloom. For this reason, heating devices are positioned on the upper part of the bloom before the first straightening module and between the first modules. The heaters are composed of ceramic flameless gas burners, installed on top of the insulation and equalization tunnels.

![Fig. 2](image1.png)

Fig. 2 shows how the strand heaters maintain the temperature during straightening.

![Fig. 3](image2.png)

Fig. 3: Strand heater and equalization tunnel scheme

**Straightening units:** The straightening and unbending unit consists of 6 double modules, each with 2 pairs of rolls. The geometrical unbending concept has 6 unbending points which allow a smooth distribution of the unbending strain. The holding force again is distributed over all modules. Independently from the oversize blooms, the design of the modules is strong enough to perform mechanical soft-reduction [2].

![Fig. 4](image3.png)

Fig. 4: Straightening units are sized to perform mechanical soft reduction

**Top feeding dummy bar system:** Production time is of essence and therefore nonproductive time must be brought to the minimum. This CCM has been equipped with a top-feeding dummy bar system successfully adopted in other SMS Concast bloom casters to reduce the
CCM down-time caused by restranding between one sequence and the next. Time studies have shown that this nonproductive time can be reduced by approximately 23% when casting the smaller sections on three strands compared to bottom-feeding; the situation is much different and much more advantageous when large sections with low casting speed are produced. In this case the time saving is 65% compared to bottom feeding dummy bars.

![RESTRANDING TIME: TOP Vs. BOTTOM FEEDING](image)

Fig. 5: comparison of restranding time with top / bottom feeding dummy bar

4. The right unbending and cutting temperature

The above represents the most troublesome metallurgical dilemma. In fact defining the total surface strain for the maximum section size on a bow caster together with the expected surface temperature before entering the unbending zone is rather complicated. The need to keep the unbending strain low and consequently adopt a large radius goes against the necessity to assure the strand surface temperature being high enough to meet the ductility window and avoid the possibility of unbending cracks.

The chemical composition of the steel grade defines the “low ductility range” and some typical values are shown below:

<table>
<thead>
<tr>
<th>Steel Grades</th>
<th>TSur,crit</th>
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<tbody>
<tr>
<td>Low alloy grades, Bearing Steel</td>
<td>&lt; ~800°C</td>
</tr>
<tr>
<td>Micro-alloy grades with V, B, Nb, high N</td>
<td>850 – 950°C</td>
</tr>
<tr>
<td>High S, Cr+Ni+Mo &gt; 1.5%</td>
<td>950°C</td>
</tr>
</tbody>
</table>

Table 2: Critical surface temperature

The un-favorable oversize bloom caster conditions of high unbending strain and low temperature, together with the wide range of steel grades to be cast including stainless steels, require special attention in the adopted engineering solutions such as equalization tunnels and the flameless heaters described above. These assure crack-free unbending especially on the larger blooms cast at low speed.

The first issue -to keep the surface strain under control- has been solved by selecting a very big caster radius. The chosen 18 m radius is among the largest curved casters built so far.
Furthermore, the total strain is distributed over the continuous straightening zone to smoothen the straightening process. Due to the low casting speed of the big sections, the strand surface temperature drops well into the low ductility range.

To solve the temperature problem at unbending, SMS Concast has recently developed a new strand heating technology dedicated to large sections cast on smaller radius machines (e.g. casting of large beam blanks on relatively small casting radii). The same solution is adopted to increase temperature during straightening while casting big rounds at low casting speed. [2] Furthermore, steel that is "heat treated" with a flameless heater develops a fine grained acicular ferrite that resists crack propagation. The coarse grained as-cast microstructure of a micro alloyed steel grade is modified by the surface heater like in a heat treatment.

![Image](image1.jpg)

**Fig. 6:** Micro alloyed steel grade with V and N on the right a ferrite+perlite as-cast structure before heating, on the left the modified fine grained acicular structure after heating

### 5. Tailor made tertiary cooling

The discharge of the Taewoong CCM is designed in such a way that three possible cooling methods are possible depending on the specific needs of the various steel grades. The traditional pile cooling via cross transfer, cooling bed and mechanical tong is foreseen for the smaller sections with non-critical grades. Slow Cooling pits where the blooms are taken directly from the roller table with a mechanical tong and piled inside slow cooling pits (thermal gradient 5-50 °C/h); this path is mandatory for small section sizes and critical grades (such as Cr-Ni-Mo high alloyed grades or martensitic stainless steel) and preferably for all steel grades of larger sections (Ø800mm and Ø1000mm). Soaking / annealing (reheating furnaces): blooms are transferred via forklift to annealing facilities. This path is foreseen for any grades that show low temperature transformation (e.g.: martensite formation) where homogenization after casting is aimed at not only minimizing the cooling rate but also minimizing thermal gradients along the cross section [2].

![Image](image2.jpg)

**Fig. 7:** Bloom removed with the tongue from the roller table for further controlled cooling.
The tertiary cooling pattern is optimized in order to avoid tensile cracks induced by cooling, distortion/bending with tensile stresses in the section and also to eliminate the risk of hydrogen flake formation in the downstream process.

6. Bloom Quality

Up to time of writing, more than 50 heats of Ø1000 mm section have been cast without any major issues. As-cast blooms are cracks free and show a large equiaxed zone (depending on chemical composition) together with minimal center porosity or piping. The following figures 8 to 12 give some impression and first quality results for the section Ø800mm and Ø1000mm [2].

Fig. 8: Ø800mm, grade 316L, macro sample

Fig. 9: Ø1000mm, grade 1016 macro sample (left) and detail (right)

Fig. 10: Ø1000mm, grade 4140 macro sample (left) and detail at center (right)
7. Semi-Continuous-Casting-Machine

The SMS Concast Vertical Semi-Continuous Casting Machine (VERSCON) is a hybrid process that allows for the following advantages compared to traditional ingot casting: lower production costs, higher flexibility, higher quality, higher yield, high automation and low environmental impact.

The ingot casting shops are in fact designed as ‘boutique’ steel plants producing small batches of high quality grades according to the sizes required by the buyers. Due to this large customization their production is normally well below 200,000 tpy. In order to grant a solution to the large flexibility required in production and the necessity to improve the yield, usually rather poor in ingot casting, the semi-continuous casting was recently introduced as an intermediate solution between a large production caster and the conventional ingot casting.

The strand is cast continuously and vertically grating the superior internal quality features of a vertical machine. Subsequently the bloom is kept on the machine in its own steel shell until its final solidification. The process is very similar to ingot casting with a much improved yield in view of the longer bloom length that is defining the machine height. The round is the most favorable section for this process thanks to the uniform and fast formation of the steel shell and the round shape is self-supporting, unlike the rectangular shape that needs to be supported to prevent bulging due to ferrostatic pressure. In the case of the round section -in fact- no further containment is needed to support the strand below the mould. The annual production, section sizes and heat size, together with the final product define the design concept and the type of machine. This leads to highly customized machines that can be very different one to the other.

Other aspects also influence the design of the VERSCON, such as the chosen casting method that can be with a tundish, like in a conventional continuous casting machine, or directly from the ladle into the mould following the principle of the ingot route. The waiting time for the complete solidification of the bloom and the necessity of further treatments on the top of the bloom to minimize its shrinkage cavity are also important factors defining the equipment design.

8. The VERSCON equipment

The VERSCON caster can be designed with one or multiple strands as the strand number is defined by the chosen bloom length, the heat size and is limited by the maximum ladle teeming time.

Having in mind to maximize the yield, the best solution is to copy the ingot casting principle and cast directly from the ladle into the mould. In this case no tundish is foreseen thus the loss due to the tundish skull is avoided. Besides the improved yield there are also other advantages in terms of OPEX due to the refractory saving, man power savings and less equipment resulting in a less expensive machine (CAPEX). Alternatively, the top of the
machine and the casting platform can be directly derived from the conventional continuous casting machine allowing sequence casting if the teeming time so allows.

Mould and oscillation are identical to the well-proven design taken from continuous casting. Below the mould, the strand is cooled within a short secondary cooling zone. The dummy bar is mounted on a travel rack which is moved via rack and pinion vertically from mould to the bottom of the machine. An elevator table tilts the fully solidified strand into the horizontal direction. From here it is taken to post-processing e.g. tertiary cooling and cutting to length devices. Even, if also rectangular and even slab section can be cast on a semi-continuous casting machine, the focus is clearly on round sections as these do not require a long containment below the mould [2].

Fig.13: Concept drawing of a VERSCON machine

A second concept foresees the application of so-called casting cylinders, which move the dummy bar from the mould to the lowest position. Such concepts are well known in the Al- and Cu-continuous casting technology and especially suitable if the section size exceeds a certain limit (e.g. Ø1200mm up to Ø1800mm) [2].

9. Minimizing top shrinkage with VERSCON

The shrinkage of the top of the ingot has always been one of the issues steelmakers had to confront as it is the main culprit of the low ingot yield. VERSCON allows treatments on the strand top to minimize the top shrinkage. The most effective solution is to heat the bloom tip to slow down solidification by replacing the mould with a flameless burner at the end of casting. Alternatively more complicated techniques are available such as continuous feeding during solidification but they require solid skills and additional investments.

10. Influencing of the final solidification structure

One of the most critical point in the semi continuous casting process is the minimization of the center porosity. Extensive simulation based on the Niyama criterion [1] shows that the tendency for macro-pores is less compared to ingot casting but cannot be neglected. To improve the feeding in the vicinity of the final solidification a movable FEMS can be installed which stirs the melt close to the final solidification and so supports the flow of liquid steel in
the very narrow final liquid pool just before final solidification. The movable FEMS can be operated on the same rack-and-pinion support as the dummy bar [2].

Fig. 11: Simulation of solidification structure for VERSCON process, section Ø850mm, casting speed 0.15 m/min

11. The ASEAN Market

The existing ingot production facilities are expected to be an attractive market for replacement by VSCCM or large bloom casters due to the higher yield and lower operational costs. The recent trend for special steel demand growth is expected also in the ASEAN even though with reduced volumes compared to other areas of the world.

Fig. 12: Ingot casting market and potential for large blooms continuous or semi-continuous casting

Recent analysis show that 2.3 million tpy of ingots are cast in the ASEAN. In view of the world globalization and costs competitiveness in the Asian countries we believe there is an effective market potential for replacing the low yield ingots plants with more efficient casting machines either for continuous casting of large blooms or semi-continuous. A conservative forecast looking only into the ASEAN countries shows that at least 1.1 million tpy of ingots
production could be switched to higher efficiency casting. This number can be even higher if the export of blooms is aimed at.

12. Conclusion

We experience a market movement away from the near-net-shape idea towards casting of large blooms in order to keep higher reduction ratios during hot deformation. The oversize bloom caster set up at Taewoong – South Korea is the new trendsetter for this type of continuous casting machines up to 1,000 mm dia. since the steel quality and internal bloom sanity is proven to be outstanding. This proves that large sections can be cast continuously replacing big ingots dedicated to forging while granting an improved yield.

Ingot producers face increasing requests to deliver ingots with CCM quality, but cannot afford the low flexibility of CCMs with high OPEX at one-heat sequences. A properly designed VSCCM has the potential to beat Ingot OPEX while keeping the same flexibility.

Since more than 60 years SMS Concast has always been the first to introduce new technologies for long products casting. Also in this case the two machines presented in this paper are matching different production targets for oversize blooms: continuous casting process for higher production facilities and semi continuous casting for on-demand production as alternatives to today ingot casting. In both cases the improved productivity, the lower OPEX and the increased yield are the decisive factors to move to these modern technologies.

References